LESSON 40 – USING THE INFRARED
(Application Exercise 6 Due)
It's just another portion of the electromagnetic spectrum, but it brings up a whole new set of problems. Here, we'll look at several types of IR seekers, seekers for missiles and the holy grail of the IR world, a usable IRSTS.

Reading:
Shaw **pp. 39 (last paragraph) to 40**
Solid State Primer Handout
Problems/Questions:
Finish Application Exercise 6, Work on Problem Set 5
Objectives:
40-1 Know the part of the EM spectrum used for IR threats.
40-2 Understand basic solid state band theory
40-3 Understand the different consideration used for seeker design.
40-4 Understand how an IRSTS is used, why they could be so effective, and their limitations
40-5 Know the different types of IRCM and how they are used.

Last Time: Jammer Lab

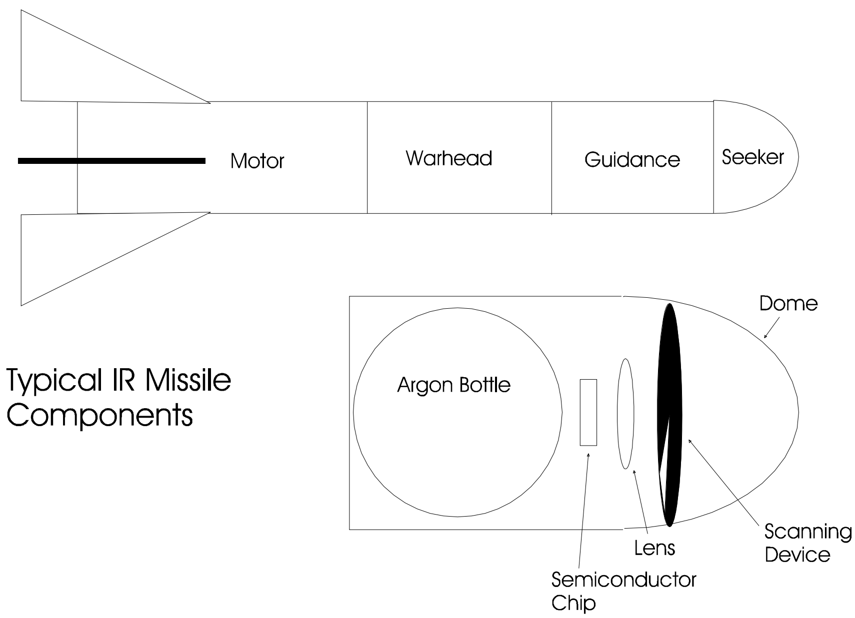
Today: IR Missiles
- Employment
- Design
  - Solid-State Seekers
- IRCM/IRCCM/IRCCCM…

Show F-15 intercept with AIM-9 (10:30 on F-15 Radar Basics tape)

Discuss heaters as another use of the EM spectrum

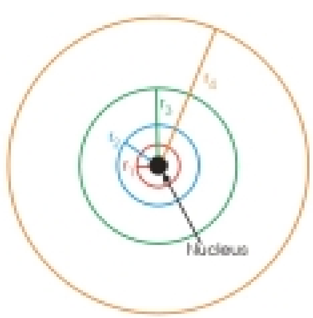
Discuss passive vs. Active detection and targeting.
- Which is better?
- What types are IR and radar?

So how do heaters work?



IR energy passes through the dome and onto the spinning scanner, which only allows energy from one direction at a time to pass. It is then focused by a lens onto a semiconductor chip that is sensitive to IR energy. By sensing when the IR energy is received and correlating this to where the scanner is looking at that time, the missile guides to an IR source.

The sensor chip is the key to the system. Knowing how it works is the way to be able to effectively employ or defeat the IR missile.

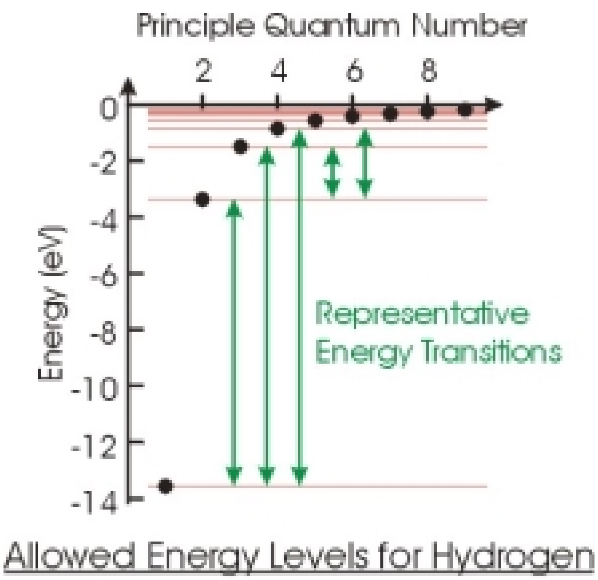


In order to understand the chip, we need to go back to Phy110 and reexamine the Bohr atom. In the Bohr atom, the only stable orbits are orbits which satisfy the relationship between r and the orbit number as $r_n = n^2 a_0$ where n is a positive integer and a_0 is the Bohr radius. Applying the Coulomb force law from Physics 215, Newton's second law from Physics 110, and the definition of the Bohr radius, we find that for the simplest atom, hydrogen, the energy of its electron can only take on the values $E = -13.6\text{eV}/n^2$, where n is any positive integer and an eV is just a unit for energy.

This equation says that atoms can only have certain discrete energies for their electrons. In our example of hydrogen, the allowed energies are thus -13.6, -3.4, -1.5, -0.85, -0.54, etc. eV. The relationship and derivations are more complex for atoms other than hydrogen, but very similar.

In all atoms, the outermost electron is the most loosely bound, meaning it's pretty easy to excite it to higher energy levels, so we'll neglect the others in the following discussion.

The Bohr atom is a convenient mental model for electron orbits. It is not the way things really work, but…



Instead of looking at circular orbits, let's look instead at the allowed energies for these circular orbits. These diagrams are called energy diagrams and have position on the horizontal axis and energy on the vertical axis.

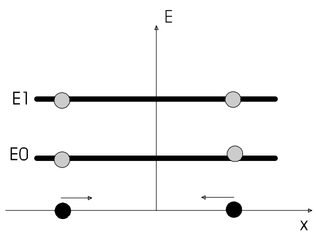
To get an electron to move from one level to another, we must add specific amounts of energy. To go from E_0 to E_1, we find the energy difference $\Delta E_{0,1} = E_1 - E_0 = hf_{0,1}$. This says that only specific frequencies of light can be absorbed or emitted by a particular atom (use the example of line spectra).

Show slides of spectra (Fig 40.12 from Serway).

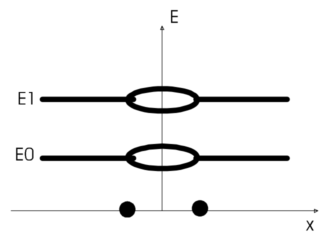
Dark = absorption (electron moves up)
Bright = emission (electron moves down)
Energy is conserved.

These graphs are for gases only. In a gas, there are *large* distances between atoms.

How many electrons can be in a particular energy state in a gas? From the Pauli exclusion principle (from chemistry and Phy110) there can be only two, one with spin up and one with spin down.

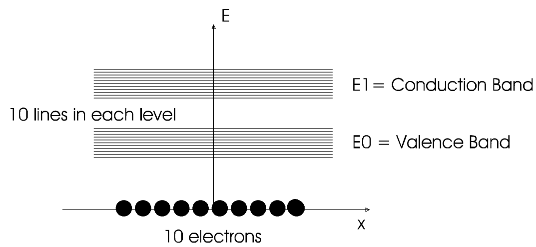


Atoms Far Apart; Levels equal.



Atoms Close Together; Levels Split.

If the electrons start coming close together, the electron wavefunctions/ orbitals start to overlap, so to keep only two electrons per state, the levels have to shift a little.



If LOTS of atoms are brought very close together, the individual energy levels blur into “continuous” bands.

So what do we know that fits the description of a whole lot of atoms very closely spaced? A solid. But to ensure that the spacing between the bands doesn’t vary too much from place to place, the atoms must be spaced very regularly. This type of solid is known as a crystal.

Now that we’ve discovered the allowable energies for electrons in the crystal, let’s see where they probably are. (Just because they’re allowed to be in a certain energy state doesn’t necessarily mean they’ll be there.)

Near the turn of the last century, two scientists (Paul Dirac and Enrico Fermi) were busy writing the fundamentals of quantum mechanics. They derived statistics that describe at which energies that particles which can have spin ±½ will be.

Basically, their statistics say that $F(E) = \dfrac{1}{1+e^{(\frac{E-Ef}{kT})}}$ where F(E) is the probability that an electron is in the energy state E. E_f is a specific value of energy called the Fermi energy, which is different for each substance.

Show slide from Fermi.mcd that demonstrates F(E) for several temperatures.

Give the display out as a handout

All this means is that the higher the temperature, the more electrons are in the higher energy states.

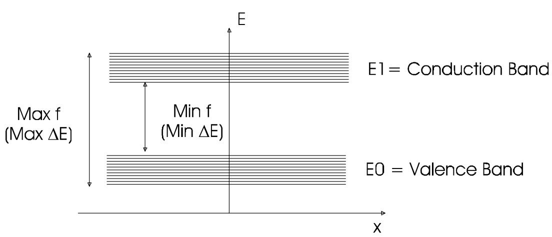
So why do we care about whether the electrons are in the conduction band or the valence band?

Show wooden band model with marbles. Full band = no current = insulator. Empty band = no current = insulator. Few holes/electrons in a band = current = conductor.

We want to be able to detect an IR source with a semiconductor chip. How do electrons get into the conduction band?

Thermally (for our case, let's assume that the number of thermal electrons is very near zero)

Add energy from a photon!



Bandwidths and bandgaps determine what photons will be detected.

Use marble model to show signal detection.

Now, what if the number of thermal electrons is significant? We get noise in the system (noise is a signal without having the desired stimulus). In order to see our signal over the noise, we need a much stronger signal.

The solution to this is a cooled detector/doped semiconductor. Limitations to this are that the dome gets hot from air friction.

IRCM

Now that we know how the signal is detected, let's look at counters to it.

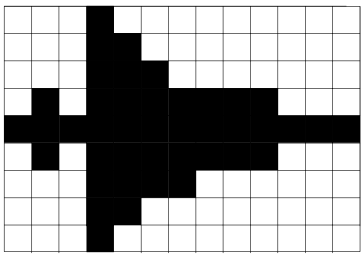
Flares try to put out the same wavelength light as the hot exhaust of the jet, but at much higher intensity. Similar idea to the way chaff counters radars. "Rise-time" is a critical factor for flares.

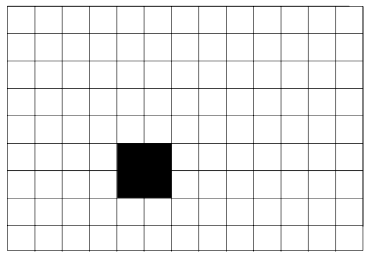
Cooling the exhaust causes a shift in the peak of the emitted wavelength, hopefully putting it out of the bandgap of the seeker.

Cooled seekers can shoot you in the face, so cooling the exhaust won't do much good.

IRCCM

The current trend is away from single detector scanned seekers toward imaging focal plane arrays. These arrays actually form a picture of the heat source.





This implies the need for some sort of artificial intelligence as the target recognition mechanism.

IRCCCM

3-5 μm lasers which detect incoming missiles and target their seekers with lasers to blind the seeker.